AN EXPERIMENTAL TEST OF CHARGE SYMMETRY IN n-p SCATTERING

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We have previously[1] outlined the scientific motivation and the basic measurement plan for our experimental search for charge-symmetry breaking (CSB) in the scattering of 200 MeV polarized neutrons from polarized protons. During the past year, significant progress has been made on all aspects of the extensive equipment development needed for the CSB experiment, and we now envision initiating measurements with polarized beam and polarized target during 1982. In the present section we provide an overview of the status of the necessary equipment, a summary of the apparatus test runs performed during the past year, and a brief outline of our proposed series of runs for the next year. More detailed descriptions of the design and operation of the polarized-neutron beam line, the multi-wire proportional chambers for ray-tracing of scattered protons, the large-volume position-sensitive liquid scintillator detectors for scattered neutrons, and relevant data acquisition hardware are given in the technical section of this report.

Construction of the polarized-neutron beam line is now well under way and completion of the facility is expected in spring, 1982. The cryostat, gas handling system, and safety venting system needed for the liquid deuterium neutron production target have been successfully tested in an experiment employing a liquid hydrogen target.[2] A neutron beam polarization and flux monitor, capable of giving information on the intensity and polarization profiles, has been designed; it will be constructed shortly and calibrated in an experiment described below.

Recent advances on the "spin refrigerator"[3] polarized proton target being developed at the University of Wisconsin include: completion and successful operation of the ^{3}He-^{4}He refrigerator; cooling of the dewar and contents to 0.6°K; fabrication, testing, and installation in the dewar of the superconducting coils to produce the polarizing and holding fields; preparation and rotation within the dewar of the first Yb-doped yttrium ethyl sulfate (YES) samples. Measurement and optimization of the YES target polarization now await only the completion of an appropriate NMR monitoring system.

Figure 1 contains a schematic illustration of one arm of the left-right symmetric detector arrangement for the CSB experiment. The two wedge-shaped plastic "start" scintillators S1 are currently being fabricated. The first x-y pair of small multi-wire proportional chambers (MWPC's W1 and W2) and a 12-cell prototype of the large-volume liquid scintillation detector (S2) have been constructed and successfully tested in beam (see below). The first large MWPC has recently been completed and is now being tested with radioactive sources, in parallel with the ongoing construction of the remaining small MWPC's. The design of the large neutron detectors is complete, and

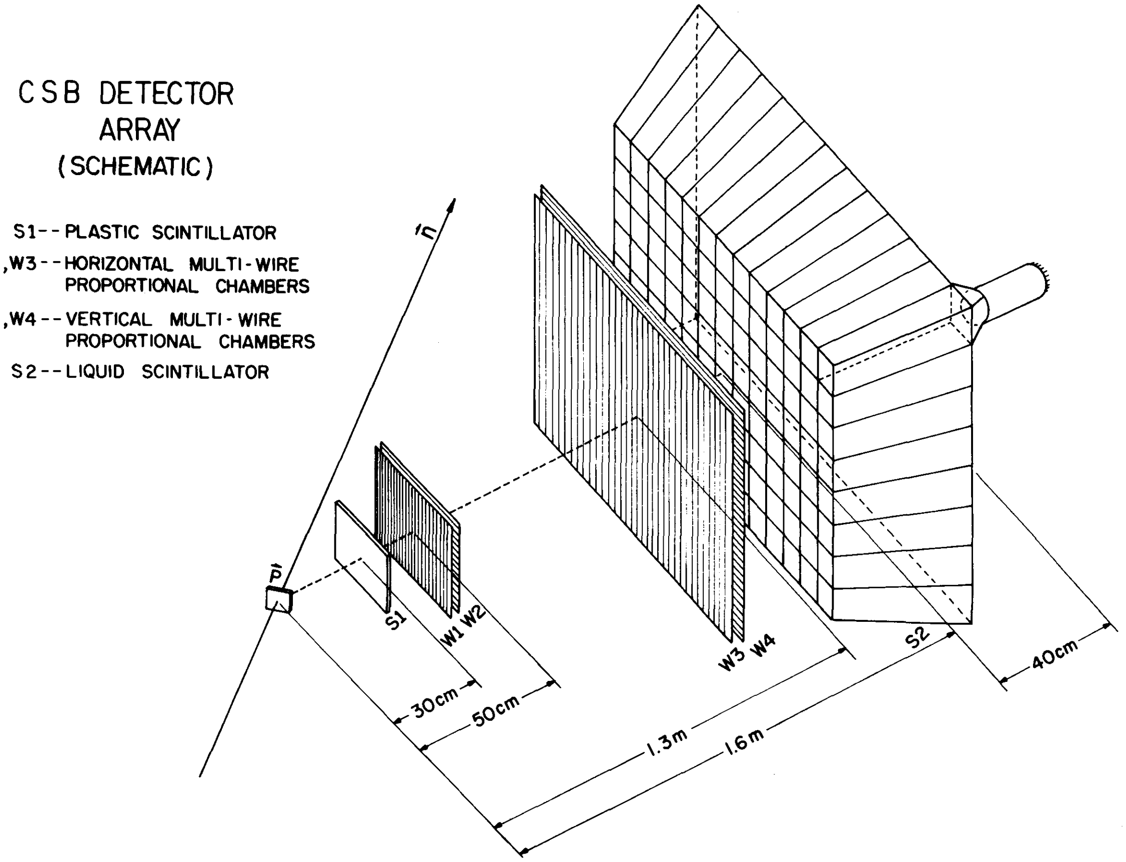

Figure 1. Schematic illustration of one arm of the left-right symmetric detection apparatus planned for the CSB experiment. Only the active areas of detectors are indicated. The outline of the corner subcell of the large-volume liquid scintillator is indicated by dashed lines. A separate phototube will be mounted at the rear of each of the ~100 subcells.

fabrication will begin shortly. Phototube base circuits for the neutron detectors have been designed and built at Hope College. Mechanical assembly of the bases is now under way, as is testing of a laser light-pulsing diagnostic system for the ~200 phototubes to be used in the experiment. A Monte-Carlo code to simulate the neutron detector response, including possible spin-dependence of the response, is now operational.

The signal processing electronics and computer interface hardware for the CSB experiment have been designed in detail; the required commercial modules have already been purchased, and about half of the needed lab-built units are presently ready. Recent CSB equipment test runs have led already to considerable improvements in count-rate capabilities and flexibility of the data acquisition program RAQUEL, and have helped to define the on-line sorting options which we will need in the experiment. Detailed consideration is now being given to possible sources of systematic error in the CSB experiment which we have neglected previously and which may require additional equipment or measurements to monitor and control.

We have used beam time sparingly to date, but with increasing regularity in recent months, as a significant fraction of the detection equipment has become available for testing. In particular, in three recent runs we have brought on-line a substantial amount of new equipment, which has worked remarkably well on the whole. These included:

1) A three-shift run in July 1981 which served as a test of the first small MWPC for CSB, of improvements to RAQUEL and to the MWPC readout electronics, and of a subset of the clear and busy circuitry intended for the CSB logic. We detected protons of ~50 to ~100 MeV from elastic scattering from CH_2 and CD_2 targets in order to plateau the chamber, measure its position resolution, and test two different schemes for absolute angle calibration of the MWPC with respect to the beam (one tied to the zero-crossing of the p-p scattering analyzing power at $\Theta_{c.m.}=90°$, the second to a kinematic crossing for p-d scattering, wherein protons and deuterons in coincidence appear at the same laboratory angle on both sides of the beam).

2) A three-shift run in September 1981 whose primary purpose was to test the response of the prototype (12-subcell) neutron detector to protons and neutrons, and to test the operation of the phototube bases built at Hope College. We used the $^7Li(\vec{p},n)$ reaction at $E_p=139$ MeV and 0° to measure (a) the absolute detector (subcell) efficiency vs. (software) pulse-height threshold, (b) detector time resolution against the cyclotron RF, (c) the quality of position information, including multi-hit patterns, for neutrons vs. protons, and (d) to investigate, crudely, possible dependence of the detector response on neutron spin orientation. In this run we set up a facsimile of a single arm of the CSB detector system, including a large-area plastic scintillator and one x-y pair of MWPC's, in addition to the prototype neutron detector. We also used an electronics scheme which more closely simulated the final CSB configuration than had been used in previous runs, and transferred data to the computer through a remote CAMAC crate for the first time in an experiment. We found many new and unexpected quirks in the electronics, wire-chamber readout, phototube bases, and RAQUEL. However, all of the equipment was working successfully (and simultaneously!) by the end of the run. Event data from this run are still being analyzed for comparison with neutron detector behavior predicted by our Monte-Carlo code. In Fig. 2 we show examples of efficiency and multiple-hit probability calculations made with the code. In addition to this in-beam test of the prototype neutron detector, we are now carrying out off-line measurements, utilizing cosmic rays (which deposit energies in a subcell comparable to those resulting from a typical ~100 MeV neutron) to optimize the time resolution between different cells. Subnanosecond timing will allow us, at least in some cases, to distinguish the first among multiple fires in non-adjacent subcells, and hence to constrain the incident direction of a neutron before its first interaction within the detector volume.

3) In November 1981 we mapped out the angular correlation and analyzing power at $E_p=200$ MeV of $(\vec{p},pn)$ and $(\vec{p},2p)$ quasi-free scattering coincident events over the angular ranges to be covered in the CSB experiment. We used the x-y pair of MWPC's and a plastic scintillator on the primary proton arm, and a plastic scintillator plus the prototype neutron detector to identify the coincident nucleon. The $(\vec{p},pn)$ results for ^{12}C, ^{16}O, and ^{28}Si targets should allow us to assess the level of systematic error which may be caused in the CSB experiment by inaccurate subtraction from the free n-p scattering peak of $(\vec{n},np)$ quasi-free

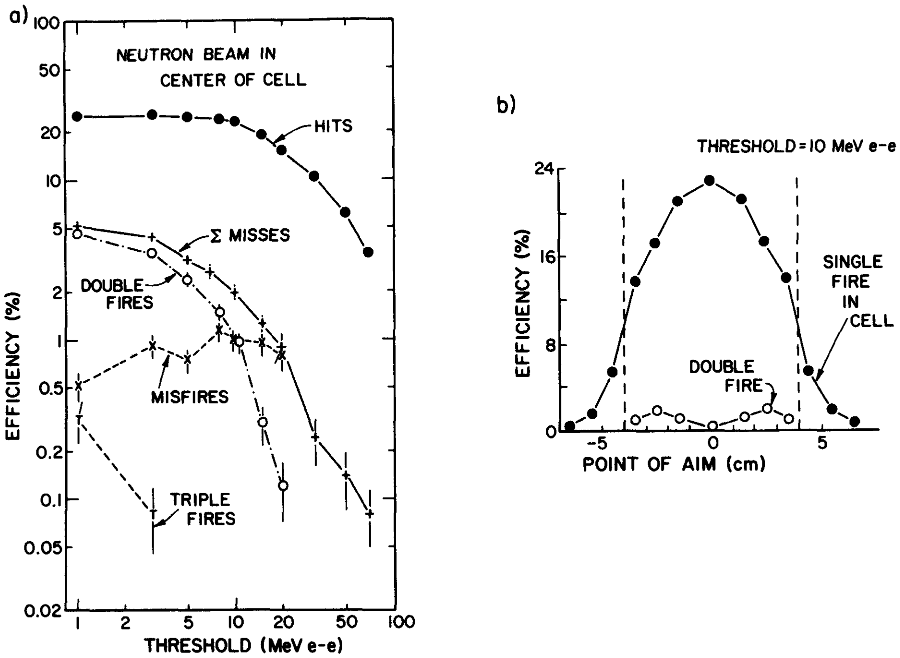

Figure 2. Detection efficiency and multiple-fire probabilities for 140 MeV neutrons incident near the center of the prototype detector, as calculated by the Monte Carlo code. In (a) the calculations are plotted as a function of detection threshold, expressed in terms of the equivalent electron energy deposited at the center of an inner subcell, for neutrons incident along the central axis of an inner subcell. Included in the plot are those events which yield a signal above threshold in the subcell of incidence ("hits"), which yield a signal above threshold only in a different subcell ("misfires"), and which yield signals in two or three subcells. In (b), single- and double-fire probabilities are plotted for fixed threshold as a function of distance of the line of incidence from the central axis of an inner subcell. The vertical dashed lines indicate the boundaries of the subcell.

scattering events from contaminant nuclei present in the polarized proton target. Since no data of this sort (nucleon-nucleon coincidences over broad energy and angle ranges, with polarized incident beam) exist at intermediate energies, it is also hoped that the results may provide useful constraints on details of the mechanism of quasi-free scattering of nucleons in nuclei. Detailed reduction of the data will begin shortly.

Representative two-dimensional spectra obtained in this run for proton-proton coincidences from a CH_2 target are shown in Figs. 3(a) and 3(b), illustrating, respectively, the spatial (x-y) distribution of protons in the wire chambers in coincidence with protons in a given subcell of the prototype detector, and the distribution of p-p coincidences (regardless of subcell) with respect to polar and azimuthal opening angles (determined from the position-sensitive detectors). These spectra indicate roughly the magnitude of the quasi-free scattering background which we may expect to see under the free-scattering peak in the CSB experiment.

Our aim in these recent runs has been, and in future runs will continue to be, to add new equipment to be evaluated to the already tested portion of the CSB apparatus, giving us extensive experience with progressively larger portions of the full setup. Wherever possible and consistent with the equipment-testing goals, we will attempt to make measurements with some intrinsic physics interest of their own, as in the case of the quasi-free background test described above. A brief outline of the future runs planned is given below:

1) Measurements at several bombarding energies of the analyzing powers $A_y(\Theta)$ for $^3H(\vec{p},n_0)^3He$ and of the outgoing neutron polarizations $P_y{}^n(\Theta)$ for $^3H(p,n_0)^3He$ will be compared to calibrate the neutron beam polarimeter, and simultaneously to cross-check the

the validity of the $P_y^n = A_y$ theorem[4] for (p,n) reactions between mirror states, on which the calibration is to be based. Recoil ^{3}He particles will be detected in the QQSP ("pion") spectrometer, in coincidence with neutrons in the beam monitor in the case of the P_y^n measurements.

2) In a series of runs after completion of the polarized-neutron facility, we will measure room background rates in the prototype neutron detector, and the energy spectrum, intensity, polarization (both vertical and horizontal components), and intensity and polarization profiles of the $\vec{n}$ beam.

3) Two short runs will be used for initial in-beam tests of the large MWPC's and of the large neutron detectors and their associated electronics.

4) In a more detailed test of the large neutron detector, we will attempt to measure any spin-dependence in its response by using a "tagged" $\vec{n}$ "beam" from the ^{3}H(p,n)^{3}He reaction, again detecting the recoiling ^{3}He in the QQSP.

5) Prior to the final CSB production run, there will then be a series of runs in which we set up the complete (or nearly complete) detector and electronics arrays, debug the system, and study systematic errors in $\vec{n}$-$\vec{p}$ and $\vec{p}$-$\vec{p}$ (null) measurements.

The above runs should keep us occupied for the remainder of 1982.

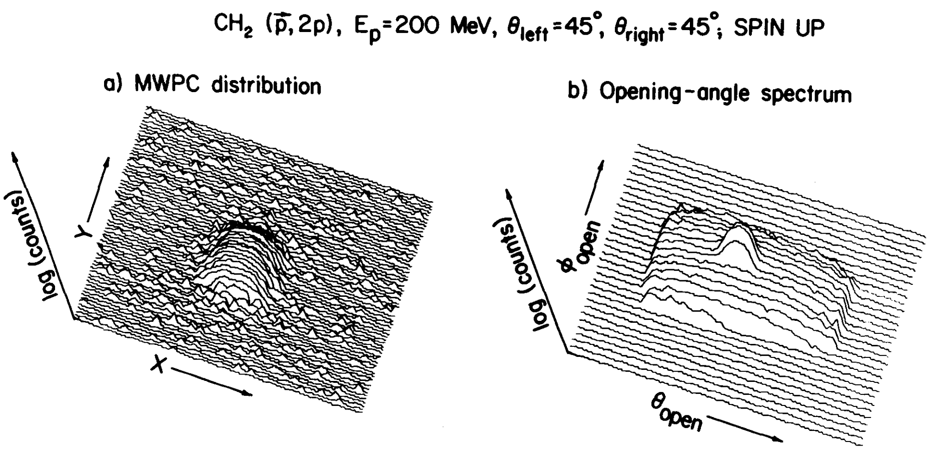

Figure 3. The distribution of proton-proton coincidences obtained in 200 MeV p bombardment of CH$_2$ with respect to (a) horizontal and vertical position in MWPC's at Θ_{lab}=45° to the left of the beam direction, when a proton is detected in a given subcell of the prototype liquid scintillator detector, which was centered at Θ_{lab}=45° to the beam right, and (b) polar (Θ_{open}) and azimuthal (ϕ_{open}) opening angles of the detected p-p pair, for all prototype-detector subcells. The background under the free p-p scattering peak in both spectra results from a combination of accidental coincidences and real coincidences from quasi-free scattering from ^{12}C.

1) S.E. Vigdor et al., IUCF Technical and Scientific Report, 1978 (p.15) and 1979 (p.118); S.E. Vigdor et al., Proc. Fifth Intl. Symp. on Polarization Phenomena in Nuclear Physics (Santa Fe, August, 1980), edited by G.G. Ohlsen et al. (AIP, New York, 1981) Vol. II, p. 1455.

2) H.O. Meyer et al., Contribution to this IUCF Scientific and Technical Report.

3) J. Button-Shafer et al., Phys. Rev. Lett. 39, 677 (1977).